THE EFFECTS OF COOLING WATER DISCHARGE ON THE INTERTIDAL FAUNA IN THE PORT RIVER ESTUARY, SOUTH AUSTRALIA

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Summary

THOMAS, I. M., AINSLIE, R. C., JOHNSTON, D. A., OFFLER, E. W. & ZED, P. A. (1986) The effects of cooling water discharge on the intertidal fauna in the Port River Estuary, South Australia. *Trans. R. Soc. S. Aust.* **110**(4), 159-172, 28 November, 1986.

The fauna of the intertidal mudflats of the Port River estuary has been monitored between 1972 and 1985. As a consequence of the increase in volume and temperature of warm water discharge from the Torrens Island Power Station, changes have occurred in the intertidal communities. Near the warm water discharge populations of several bivalve mollusc and worm species have been reduced or eliminated and previously rare or absent worm species have become abundant.

Changes in numbers and variety of species have been recorded throughout Angas Inlet and these changes have encroached some way into the adjoining southern reaches of Barker Inlet and the eastern end of North Arm.

Introduction

Various intertidal and shallow littoral environments can be recognised in the South Australian Gulfs. These are based on coastal topography and associated variations in energy of the wave action (Womersley & Thomas 1976). One environment, typical of the low wave energy regions of the Gulf St Vincent, north of Port Adelaide, is the extensive muddy intertidal flats backed by mangrove woodland and samphire.

Studies have been made on the subtidal fauna of such coastlines in upper Spencer Gulf (Shepherd 1983; Ward & Young 1982, 1983), however except for listings of conspicuous species (Womersley & Edmonds 1958; Butler *et al.*[1]; Butler *et al.* 1977) no detailed information has been available on the fauna of the muddy intertidal shores of Gulf St Vincent.

A number of overseas reviews have documented the effects of warm water discharges from power stations on sublittoral benthic fauna (Coutant & Talmage 1975; Talmage & Coutant 1980; Craven *et al.* 1983; Langford 1983). Effects vary from site to site as a function of the climatic, hydrological and biological features of the sites (Crema & Pagliai 1980). Generally greatest effects on subtidal fauna are observed very near the outfalls and particularly during the hottest times of the year (Langford 1983). The effects include a significant reduction in numbers of species within the influence of the warm water plume (Warinner & Brehmer 1966; Thorhaug *et al.* 1978) with, in some cases, the establishment of dense populations of a few thermally tolerant species (Bamber & Spencer 1984). There is a lack of similar information on the influence of warm water outfalls on intertidal mudflat fauna (GESAMP 1984).

This paper describes a monitoring programme conducted between 1972 and 1985 to establish long term patterns of faunal distribution of the intertidal mudflats of the Port River estuary. It describes changes associated with changing water temperatures resulting from the incremental development of the cooling water (CW) system of Torrens Island Power Station.

Materials and Methods

The study area

The Port River estuary is a sheltered water complex of mudflats, mangroves and samphire marshes dissected by narrow channels with only a small and intermittent inflow of fresh water (Fig. 1). Torrens Island Power Station commenced operating in 1967. It takes in cooling water from the channel floor near the Port River, North Arm junction and discharges warm water at the surface in western Angas Inlet.

Average ambient summer (intake) temperature in the estuary is about 25°C (Robertson 1971; Neverauskas & Butler 1982). By 1972 Torrens Island Power Station, A Section, was discharging 1.9×10^6 m^3/day of sea water at 6–7°C above intake temperature. Since then there have been increases in the volume of warm water discharged as a further four B Section units have become operational.

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[1] Butler, A. J., Depers, A. M., McKillup, S. C. & Thomas, D. P. (1975) The Conservation of Mangrove Swamps in South Australia. Report to the Nature Conservation Society of South Australia (Unpublished)

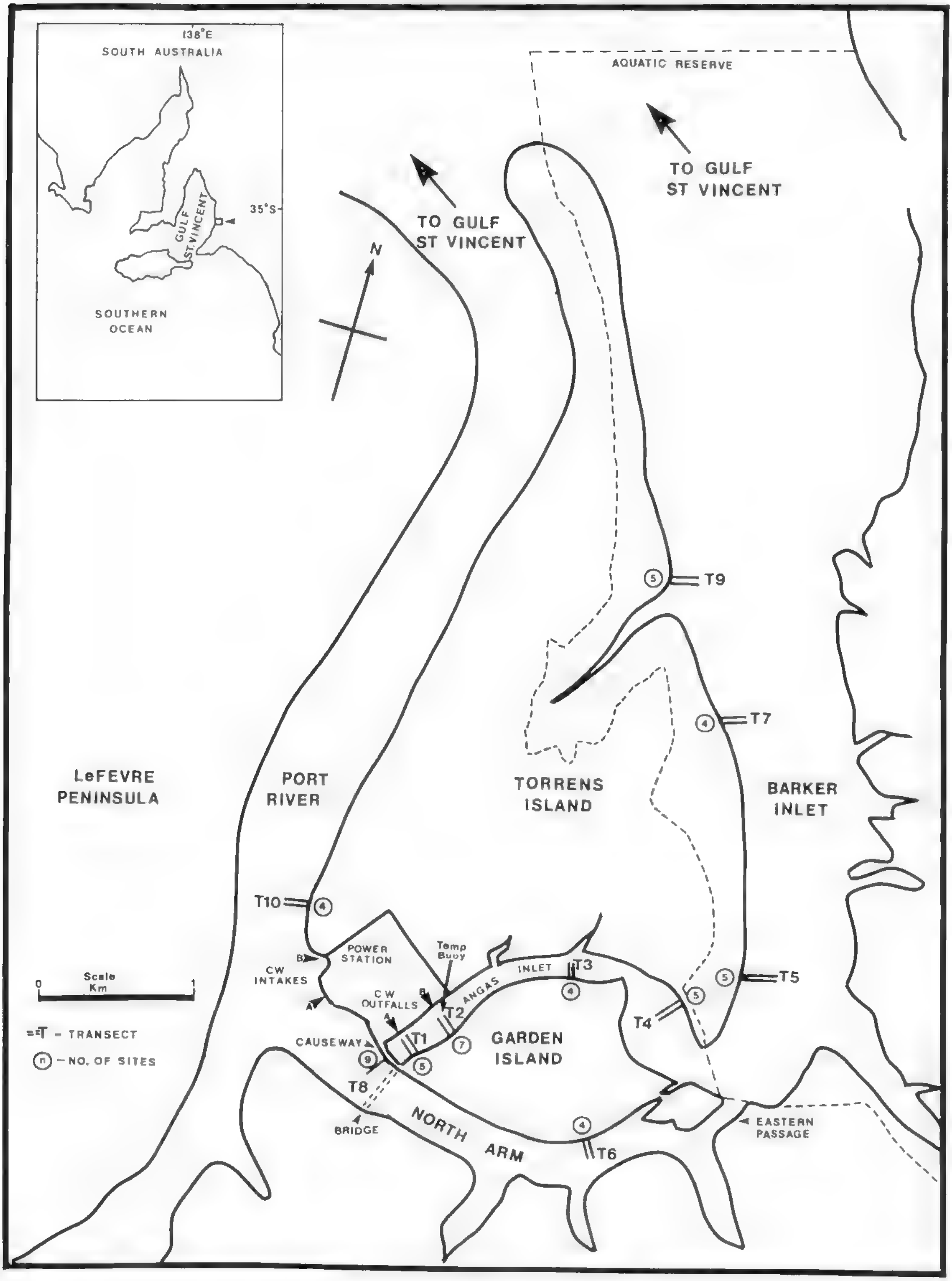

Fig. 1. Transect locations in the Port Adelaide estuary.

Presently B Section discharges an additional 2.0×10^6 m^3/day of warmed water to Angas Inlet at 9-10°C above ambient temperature.

Water temperature

A half hourly record of intake temperatures at the junction of the North Arm and the Port River was maintained and a similar record was made of warmed effluent water from the power station. From 1979 a record of temperatures at half hourly intervals was made with a thermistor suspended from a buoy 30 cm below the surface in Angas Inlet (Fig. 1). A continuous record was also made of shade air temperatures at Torrens Island. Average weekly temperatures were abstracted from these records.

A series of temperature surveys was carried out during hot summer weather in March 1972, February 1979 and January 1982 to define distribution of warmed water through the estuary for both dodge (Bye 1976) and spring tides. Each survey involved from three to five circumnavigations of Torrens Island with surface temperatures recorded at 28 stations spaced throughout the estuary. By recording several times a day at each location it was possible to graph the results with time and tide to obtain a representation of simultaneous temperatures throughout the estuary.

On 4.ii.1984 a digital image of the distribution of the warm surface water from the Torrens Island Power Station was obtained at 9.00 a.m. on a falling tide. The image was produced by Hunting scanning equipment operated from a Lear Jet at an altitude of 3 km.

Intertidal fauna

Sampling methods were based on those of Zed[2], so that data comparable to this first study of the intertidal fauna in this region could be obtained.

This involved sampling on a series of transects established on the main branches of the estuary at varying distances from the warm water discharge of the power station. In 1972 (Zed[2]) and 1977 five transects were examined. Subsequently five further transects were established (Fig. 1). Each transect extended across the intertidal mudflat from 10 m seaward of the mangrove fringe to the low water mark (LWM). On each transect stations were established at 10 m intervals numbered from the mangrove fringe (e.g. for transect 1, stations 1.1, 1.2, 1.3 . . . etc.). Number of stations per transect depended on the width of the intertidal mudflat at low tide, ranging from 4 on transects 3 and 7 to 9 on transect 8.

At each station, on each sampling occasion, four samples of surface area 0.03 m^2, depth 10 cm, were collected on a line perpendicular to the transect. These samples were combined. All animals retained on 1 mm mesh sieves were counted and sorted. For all but the first two surveys (1972 and 1977) all specimens were preserved, polychaetes in 10% formalin and other animals in glycerol:water: ethanol (5:25:70 v/v).

For each survey, using averaged station data, the Bray-Curtis measure was used to produce a similarity matrix for the transect faunas, after root-root transformation of the data (Swartz 1978; Field *et al.* 1982).

Sediments

In March 1982 sediment samples were collected in the same manner as the intertidal fauna samples from a total of 49 stations for all transects (Fig. 1) and passed through a series of calibrated sieves to determine weights, expressed as a percentage of total sample weight of various sediment grades. The sediment grades corresponded to Wentworth size classes (Folk 1968) with the modification that the largest grade discriminated was coarse sand (including all material coarser than 1.25ϕ) and the finest sediment grade discriminated was silt (3.75ϕ).

Graphic Means (Mz, Folk 1968) were determined for the samples. The Bray-Curtis dissimilarity measure (Swartz 1978; Field *et al* 1982) was used to classify the samples into groups according to similarities based on the percentage contribution particular sediment grades make to the total weight of the various samples (Miedecke & Stephenson 1977).

Results

Temperature

Temperature records for summer seasons for 1972, 1977, 1983 and 1985 are given on Fig. 2.

Allowing for differences in weather between years (air temperature, Fig. 2) similar ranges of summer ambient water temperatures have been observed for the years 1972, 1977–83 and 1985. Torrens Island B Section discharges water at a higher temperature than A Section, therefore peak summer discharge temperatures since 1978 are higher than those of 1972 and 1977 when only A Section was discharging (Fig. 2).

Temperatures recorded at the Angas Inlet buoy since 1979 tend to follow discharge temperatures, being about 2-4°C lower, due to mixing with cooler tidal water. Very near the discharge to Angas Inlet the maximum temperature increase above ambient water temperature is determined by a number of

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[2] Zed, P. A. (1972) The Effect of Warm Water from the Torrens Island Power Station on the Marine Fauna of Angas Inlet. B.Sc. (Hons) Thesis, Zoology Department, University of Adelaide. (Unpublished).

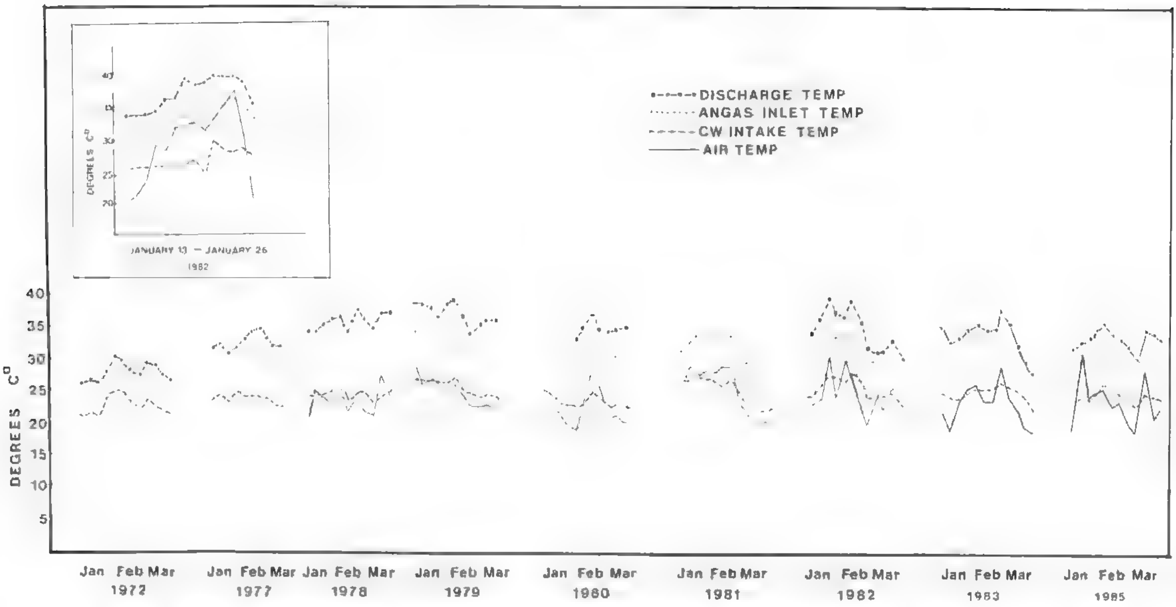


Fig. 2. Weekly average temperature data for ambient, Angas Inlet, and cooling water (CW) outfalls, for January-March of 1972, 1977-1983, and 1985. Inset: Typical short term summer extremes (January 1982). Note: 1972 plots show "A" station discharge temperatures, 1977-1985 shows "B" station discharge temperatures.

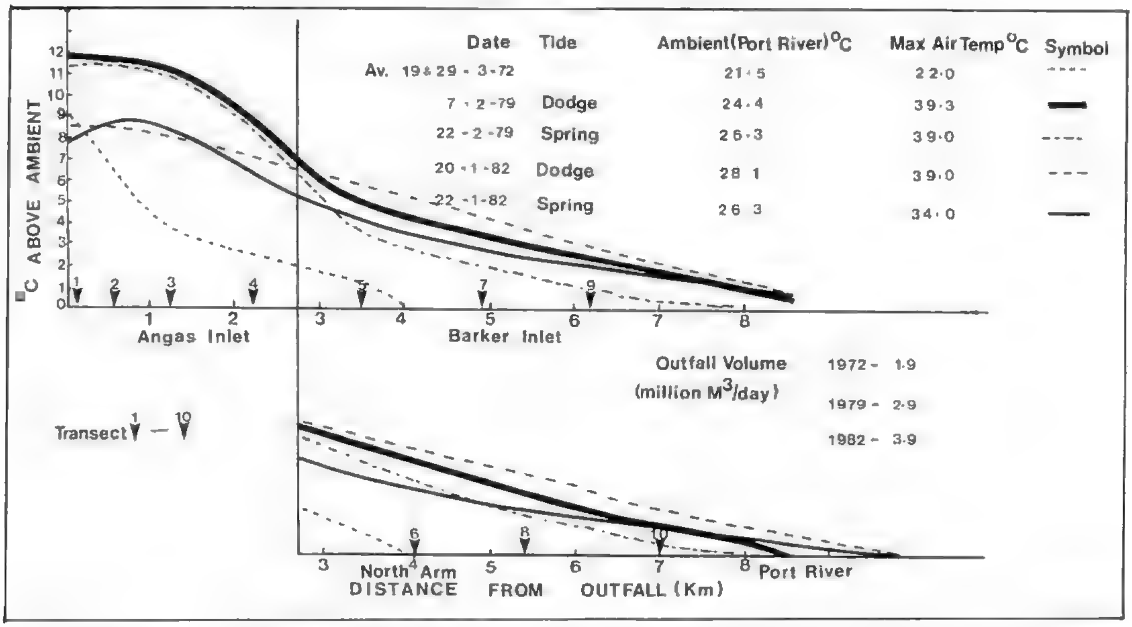


Fig. 3. Gradients of above-ambient temperatures from the CW outfalls to more remote regions of the Port River "estuary" for selected days in 1972, 1979 and 1982.

factors such as load on the power station units and local meteorological conditions (wind speed and direction). With progressive increase in the volume of warm water discharged to Angas Inlet, above-ambient water temperatures are measured over a wider area (Fig. 3). Further, during dodge tides when there is little tidal dilution of the discharge water, warm water tends to bank up through Angas Inlet. Temperatures of up to 40°C have been recorded in Angas Inlet with the power station discharging from all units in hot weather on days of little tidal movement (Fig. 2 inset). The digital image of the warm surface water distribution in February 1984 (Fig. 4) shows the major influence of the discharge extending throughout Angas Inlet to southern Barker Inlet and eastern North Arm. There is some recirculation of warmed surface water around Garden Island to the Port River and also incursion to the southern region of Barker Inlet (see also Fig. 3, 1982 spring tide). This influence is not observed at the deeper power station intakes.

Intertidal fauna

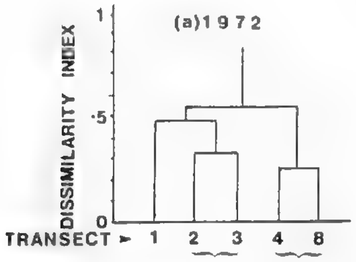
A total of 120 species were recorded. Polychaetes were the most numerous (40 species), including several new records for southern Australia, followed by crustaceans (37), gastropod molluscs (19), bivalve molluscs (13), and 11 species from various other taxa (Appendix 1).

Fig. 5 shows the dendrograms of classification of transects by faunal homogeneity for 1972, 1977 and the summer surveys of 1981, 1982, 1983 and 1985. Species characteristic of the identified groups of faunas are shown in Fig. 5, with their percentage contribution to the total population sampled on the transects of the group.

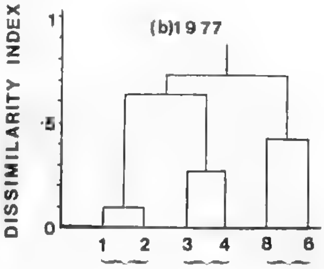
Fig. 4. Thermal image of surface water distribution on a falling tide in the Port River estuary, February 1984 (CW in 23.4 °C, CW out 33.4 °C, Angas Inlet 28.6 °C). The pale area in Angas Inlet, around Garden Island, and tailing into North Arm shows the distribution of the warm surface plume.

There have been some difficulties in proceeding with the Bray-Curtis analysis. In retrospect the decision to continue the sampling design adopted by Zed^2 caused some problems in analysing the data, as numbers of stations were not consistent between transects. However, as the faunal homogeneity analysis depends on the "percent each species contributes to the total number of individuals collected", rather than absolute numbers (Swartz 1978), we contend that this approach fairly describes the significant changes in faunal patterns in the estuary. Consistent patterns within the long term data support this contention. For the 1972 and 1977 surveys, identifications of some polychaete species were uncertain and, with the exception of the cirratulid *Cirriformia punctata*, and the large tube dwelling species *Chaetopterus variopedatus* and *Diopatra dentata*, specimens were listed as "polychaete sp 1", "polychaete sp 2", etc. Because of the taxonomic uncertainties and the absence of preserved specimens from these two surveys, these unidentified polychaetes were lumped together for the Bray-Curtis analysis. Reference to the original data (Zed^2) and to subsequent work, suggests that transects most remote from the outfall (transects 4 and 8) do not share the same unidentified polychaetes as the transects closer to the outfall (namely transects 1, 2 and 3). Grouping of transects on the dendrograms based on lumped polychaetes should therefore give a conservative picture of faunal homogeneity relationships, with differences between transects under, rather than over-emphasised.

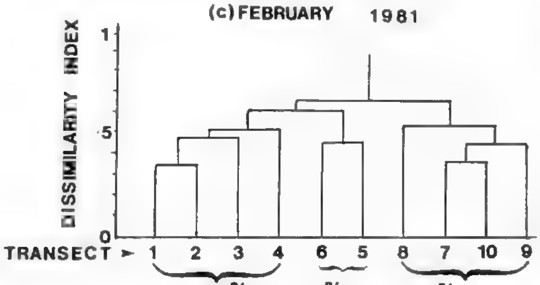
The 1972 dendrogram showed three main groups of transects with respect to their faunal homogeneity (Fig. 5). The fauna of transect 1 directly opposite the thermal outfall was dominated by *C. punctata* which comprised 86% of all organisms found on this transect (Fig. 5a). A few "other polychaetes" and low numbers of one species of bivalve, *Tellina deltoidalis* were also found on this transect. On transects further from the outfall (2 and 3) low numbers of *C. punctata* were found with the community dominated by "other polychaetes", *T. deltoidalis* (25%), and the gastropod *Nassarius burchardi* (Fig. 5a). Although transect 1 and transects 2 and 3 share some species (namely *C. punctata* and *T. deltoidalis*) the difference in relative contributions which these species make to the communities of each transect results in transect 1 clearly separating from transects 2 and 3 on the dendrogram. No *C. punctata* were found in the communities most remote from the outfall (transects 4 and 8, Fig. 1). Although "other poly-



		%	%	%
Worms	C. punctata	86	11·6	
	D. dentata	2	1·2	4
	'polychaetes'	11	58	7·7
Molluscs	X. inconstans			77
	I. crebrelamellatus			2·2
	T. deltoidalis	2	25	6·6
	L. recta			2·2
	N. burchardi		3·1	

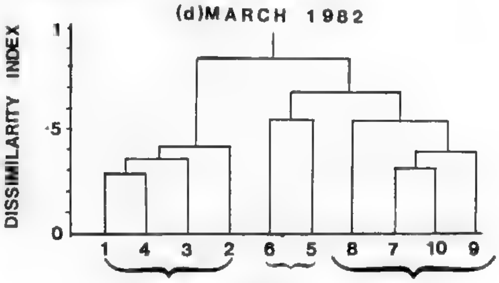


		%	%	%
Worms	C. punctata	98	13	
	D. dentata		3·8	1
	'polychaetes'	1·5	10·3	24·8
Molluscs	X. inconstans			42
	I. crebrelamellatus			27·8
	T. deltoidalis		69	1
	B paivae			2·8
	N. burchardi		2·9	

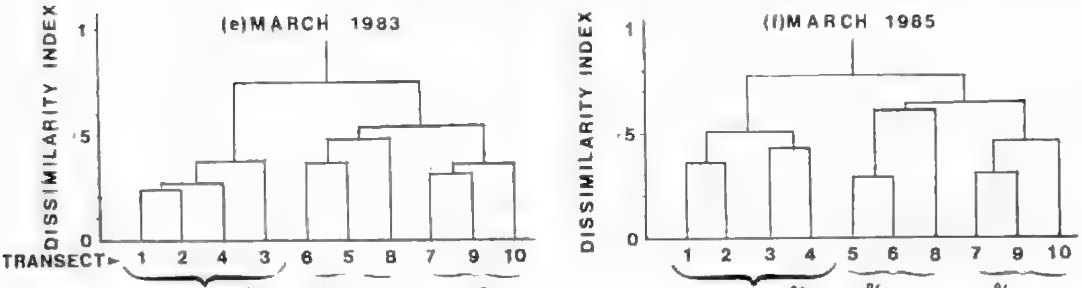


		%	%	%
Worms	C. punctata	17	86	
	Pseudopolydora sp.	5		
	N. grubei australis	5	4·1	
	N. australiensis			1
Molluscs	X. inconstans	51‡		47
	I. crebrelamellatus		2·1	1·3
	T. deltoidalis			2
	K. scalarina & K. peroni			1
	S. fragilis	17·5		41
	N. pauperata			2·9

‡juvenile specimens



		%	%	%
Worms	C. punctata		83	
	Pseudopolydora sp.	96		
	N. grubei australis		5	
	N. australiensis			5·3
	S. cylindrifer			5·6
	N. vaalii			2·7
Molluscs	X. inconstans	1·5		50
	I. crebrelamellatus		6·7	11·2
	T. deltoidalis		2	3
	K. peroni			1·5
	N. pauperata			1
	S. fragilis			1
Anemone	A. albocincta			8·2



		1 2 4 3 %	6 5 8 %	7 9 10 %
	C. punctata		75	1·3
	Pseudopolydora sp	91	2	
Worms	N. grubei australis	2·3	3·8	2
	N. australiensis			8
	S. cylindrifer			27
	N. vaalii			3
	B. lepte		3	2
Molluscs	X. inconstans	6·2	6·8	28
	I. crebrelamellatus		5·9	·9
	T. deltoidalis			6
	K. peroni			
Anemone	A. albocincta			7·5

		1 2 3 4 %	5 6 8 %	7 9 10 %
	C. punctata	5·5	74·2	
	Pseudopolydora sp.	62		
	N. grubei australis	1	3·5	
	N. australiensis			7·2
Worms	S. cylindrifer		1·4	29·2
	N. vaalii		2	
	S. gracilis	3·2		
	C capitata	2·2		
	Terebellinae			1·4
	X. inconstans	18	9·5	30·4
	I. crebrelamellatus		7·4	9·4
Molluscs	T. deltoidalis			6·7
	S. fragilis			
	N. trigonella	1		
	N. burchardi			1·6
Anemone	A. albocincta			3·6

Fig. 5. Dendrograms of transect faunal homogeneity, for surveys of 1972, 1977 and the summers of 1982-83 and 1985. The figure also lists all species which contribute >1% to total number of individuals sampled on each of the subjectively indentified groups of transects for each survey.

chaetes" contributed a small percentage to the communities of these transects, their faunas were primarily distinguished by the large numerical contribution of *Xenostrobus inconstans* (77%) and other bivalve molluscs (Fig. 5a).

In 1977, with an additional 1×10^6 m^3/d of warmed water discharging to Angas Inlet, faunas of both transects 1 and 2 were characterised by the very large numbers of *C. punctata* previously found only on transect 1. These two transects therefore formed a distinct group on the 1977 dendrogram. (Fig. 5b). Low numbers of *C. punctata* were present on transect 3 (where they had already been recorded in 1972) but also on transect 4 (where they were not recorded in 1972). These two transects (3 and 4) formed the second, intermediate group on the dendrogram, their faunas also being characterised by the bivalve *Tellina deltoidalis* and other shared polychaetes (Fig. 5b). The faunas of transect 8 and the new transect 6 were both distinguished by the varied bivalve and polychaete species which had characterised transect 8 in 1972 (Fig. 5b).

The summer of 1980–81 was the first full summer with the addition of a further unit (0.5×10^6 m^3/d) discharging to Angas Inlet. From 1980 all polychaetes were identified and numbers of every species were considered in the Bray-Curtis analysis. Faunas of transects 1 and 4 all grouped together on the dendrogram (Fig. 5c). A major contributor to the grouping of transects 1 to 4 was, again, *C.*

punctata, comprising 63% of the total number of polychaetes found on this group of transects. Two other polychaete species, namely the orbiniid *Naineris grubei australis* and the spionid *Pseudopolydora* sp. were identified in the faunas of this group, each contributing about 20% to the total number of polychaetes. It is possible that these two species are the unidentified polychaetes found in association with large *C. punctata* numbers in the previous surveys. Unexpectedly, another contributor to the grouping of the faunas of transects 1 to 4 was the mud mussel *Xenostrobus inconstans* which occurred in each of these transects, comprising 51% of all organisms of this group. This mussel had been dominant in North Arm and Barker Inlet, but had not been common in Angas Inlet before 1980-81. All specimens were juvenile and subsequent surveys revealed that the species did not persist in the Inlet. A settlement of another mollusc the gastropod *Salinator fragilis* also contributed to the faunal homogeneity of transects 1 to 4, and to the high mollusc to polychaete ratio found for these Angas Inlet transects in this survey compared to all other surveys reported here. In 1981 *C. punctata* was found for the first time in large numbers on transect 6. It was also abundant on the new transect 5 in southern Barker Inlet (Fig. 1). The faunas of these two transects formed the intermediate group on the dendrogram (Fig. 5c), also characterised by a second worm species, *N. grubei australis*, and a bivalve mollusc, *Irus crebrelamellatus*.

Faunas of transects 7 to 10, forming the third group on the dendrogram, were again characterised by the varied bivalve mollusc populations. On this group of transects the polychaete to mollusc ratio was low. The most abundant worm, *Nephtys australiensis*, comprised only 1% of the total number of organisms (Fig. 5c). Low numbers of other worm species including *Scoloplos cylindrifer* and *Neanthes vaalii* were also identified in the faunas of this group of transects.

Following the 1981-82 summer, the first full summer with all four units of B Section operating (Fig. 3), a further change was noted in the faunal distribution around the estuary. Again the faunas of transects 1-4 grouped on the dendrogram (Fig. 5d). However the previously abundant *C. punctata* had virtually disappeared from the faunas of these transects and the spionid *Pseudopolydora* sp, which had been identified in low numbers in the 1981 survey, dominated the faunas of this group of transects, comprising 86% of all organisms found (Fig. 5d). *C. punctata* remained the predominant organism in the faunas of transects 5 and 6, which again formed an intermediate group on the dendrogram (Fig. 5d). The group of faunas of transects 7 to 10 continued to be characterised by the bivalve and worm species previously identified from areas more remote from the outfalls (Fig. 5d).

Although the volumes and temperatures of the thermal discharge underwent no further increase following the 1982 summer, surveys were continued to determine whether the 1982 dendrogram represented a stable biological state. The 1983 dendrogram closely resembled that for the previous survey with continued spionid dominance of the Angas Inlet transects, and transects 7, 9 and 10 having faunas with large bivalve populations and numbers of those worms which had previously been identified as characteristic of regions remote from the outfall (Fig. 5e). The most notable change in the dendrogram was the tendency for the fauna of transect 8 to group more closely with those of the cirratulid dominated faunas of transects 5 and 6, rather than with those of transects 7, 9 and 10. This was due to a combination of factors including an increase in numbers of *C. punctata* on transect 8, and an increase in numbers of *I. crebrelamellatus* and *X. inconstans* on transects 5 and 6. Two years later, in March 1985 the transect faunas demonstrated virtually the same homogeneity relationship (Fig. 5f). The dominant species in each of the major groups of transects remained the same (Fig. 5f) although on transects in Angas Inlet (1-4) some worm species (*Capitella capitata*, *Syllis gracilis* and *C. punctata*) were present in greater numbers than in 1983.

For the samples from 1981 until 1985, when all species were identified, it was possible to record total species number at each transect. The mean number of species per square metre for the various groups

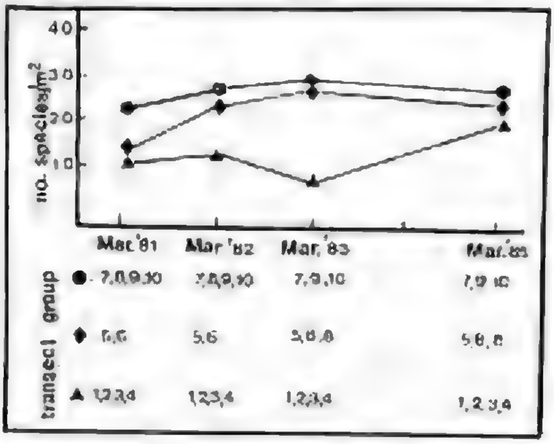


Fig. 6. Relationship between number of species/m² and transect group for the surveys of 1981-83 and 1985. All species were identified in these surveys.

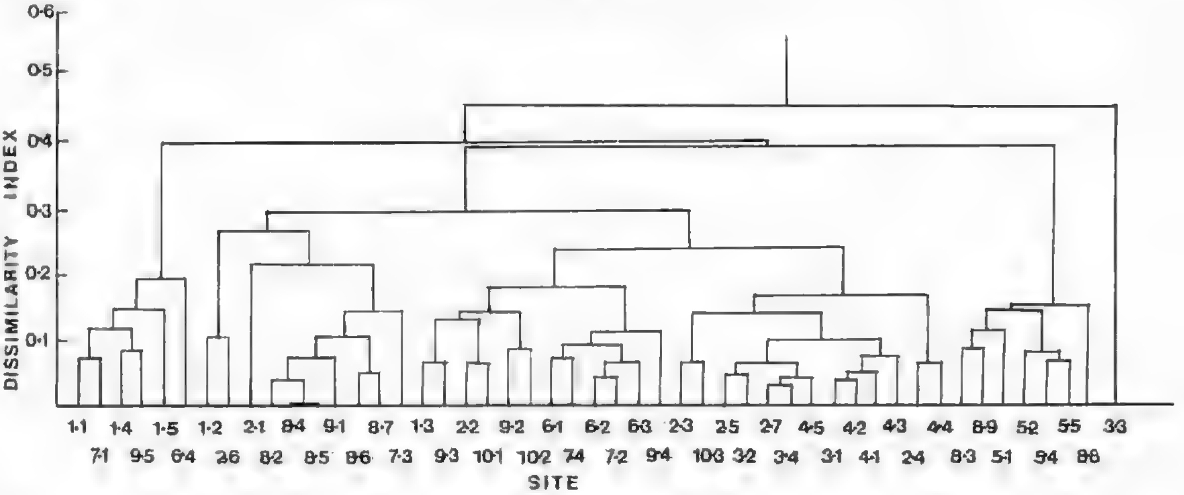


Fig. 7. Dendrogram of classification of Port Adelaide "estuary" sites by sediment grades.

of transects identified in the 1981–85 surveys is shown in Fig. 6. While all groups of transects had occasional or rare species in addition to the core of more common species (Fig. 5a–f), the total number of species in a given group of transects was consistently higher in groups more remote from the thermal outfall (Fig. 6).

Sediments

Of 49 sediment samples over half (26) were medium sand (MZ, 1–2 ϕ), 16 were fine sands (MZ, 2–3 ϕ) and seven were coarse sands (MZ 0–1 ϕ). Fig. 7 gives the hierarchical classification of the sediments from all sites sampled.

Although in a few cases similarities were observed between samples from the same transect (e.g. samples 5.2, 5.3 and 5.4 were all coarse sand, and samples from 4.1, 4.2 and 4.5 were all fine sand) overall there was no obvious topographical coherence in the clusters on Fig. 7, and no correlation between sediment and type of infauna.

Discussion

Although a number of overseas studies have documented the effects of thermal discharge on sublittoral benthic fauna, comparatively little information is available on intertidal fauna. Barnett (1971) investigated the effect of thermal discharge from Hunterston Power Station, Scotland, on selected intertidal sand animals, finding only subtle changes in breeding season and growth rates of a bivalve, *Tellina tenuis*, and an amphipod *Urothoe brevicornis*. Barnett and subsequent authors (Bamber & Spencer 1984) attibuted the small effects to the fact that the intertidal animals in cool temperate regions are adapted to a greater natural temperature range than that characteristic of the thermal effluents in these regions.

Few published Australian studies are available with which to compare the present results. Powis & Robinson (1980) examined the subtidal benthic macrofaunal communities in the Tuggerah Lakes. The Munmorah Power Station discharges water to this estuarine lake system at up to 4°C above ambient. These authors report that the only apparent influence of the warmed water was an increase in numbers of the gastropod mollusc *Velacumantus australis*, very near the outfall.

Rainer & Fitzhardinge (1981) examined both intertidal and subtidal benthic communities of Port Hacking. While species distribution was limited by fluctuations in dissolved oxygen levels there was little evidence that natural short term temperature extremes, over the shallow sand flats, influenced species distribution.

Saenger *et al* (1980) examined the macrobenthos of the Calliope River and Auckland Creek, Queensland, to obtain comprehensive prethermal baseline data prior to the establishment of the Gladstone Power Station. To date published post thermal information includes a localised study of the macrobenthos of the discharge canal of this power station. Saenger *et al* (1982) suggest that the major changes in the benthic fauna in this localised region can be more closely correlated with changes in flow rates, and ultimately with resulting sediment changes, than with temperature effects.

This study documents a pattern of change in the distribution of intertidal mudflats in response to changing environmental conditions. In 1972, near the Torrens Island Power Station cooling water discharge to Angas Inlet, the intertidal communities had a localised predominance of the cirratulid worm, *Cirriformia punctata*, and a comparative paucity of bivalve molluscs. Between 1972 and 1981 the distribution of *C. punctata* extended throughout Angas Inlet to the adjacent reaches of Barker Inlet and North Arm, while there was also a suppression of bivalve mollusc species over the same range.

Since the summer of 1981–82 *C. punctata* has been replaced as the predominant species in Angas Inlet by *Pseudopolydora* sp. a spionid which previously contributed only a small percentage to the population in this region. *C. punctata* predominance has been restricted mainly to the region of transects 5 and 6 in Barker Inlet and North Arm (Fig. 1).

The pattern of change closely corresponds to changes observed in studies of estuarine ecosystems subjected to organic pollution. Gray (1976a) and Parker (1980) have noted declines in populations of bivalve mollusc species in the fauna of polluted estuaries. Grassle & Grassle (1974) and Gray (1976b, 1980) identify various groups of organisms which, because of their life history characteristics, respond rapidly to environmental perturbations and colonise disturbed regions. Spionid worms, which presently dominate the fauna of Angas Inlet are amongst the most opportunistic colonising species. Other species presently found in Angas Inlet, the syllid and capitellid worms, are also considered highly opportunistic (Grassle & Grassle 1974).

Prior to this study *C. punctata* had only been recorded at Lizard Island, Qld (P. Hutchings 1980, pers. comm.). Angas Inlet is a boat harbour, mooring yachts from around Australia. We have recorded *C. punctata* in the fouling fauna of solid substrates in Angas Inlet, as well as in the intertidal zone. It is therefore possible that this species was introduced to the warm waters of Angas Inlet in the fouling fauna on the hull of a visiting yacht. (Note that another tropical species, the Sycophomedusan *Cassiopea ndrosia*, previously known from Fiji, New Caledonia and North Queensland (Kramp 1961, 1965) has also been found in Angas Inlet (Southcott 1982)). Little is known of the life history of *C. punctata*, but George (1964a, b) has detailed the life history of a related species, *C. tentaculata*, indicating a wide temperature tolerance in its breeding season, and the capability of rapid, massive population bursts. These characteristics, also associated with the recognised opportunistic species above (Grassle & Grassle 1974), probably enabled this tropical species to colonise Angas Inlet when the natural populations of intertidal fauna were disturbed by the development of the power station. However, *C. punctata* has not persisted as the dominant species in Angas Inlet since 1982. It seems likely that the restriction of *C. punctata* to areas just outside Angas Inlet where maximum summer temperatures are about 30°C (Fig. 3) is due simply to the temperature tolerance of this species, as it has been recorded adjacent to the outfall in higher temperatures. The sudden and drastic reduction in numbers of *C. punctata* in the warmest regions of Angas Inlet since March 1982 may be explained rather by the competitive advantage of the more highly opportunistic *Pseudopolydora* sp., in a disturbed environment where biological interactions may be more exaggerated (Grassle & Sanders 1973).

Conclusion

The progressive increase in thermal discharge from Torrens Island Power Station over the period 1972–1985 has lead to recognisable changes in the nature, abundance, and distribution of intertidal invertebrates in adjacent reaches of Port River estuary. In particular bivalve mollusc and worm species characteristic of undisturbed regions of the estuary, have declined in population in the warmest regions of Angas Inlet. They have been largely replaced by opportunistic worm species, initially the tropical cirratulid *Cirriformia punctata*, and more recently the spionid *Pseudopolydora* sp. *C. punctata* also predominates in southern Barker Inlet and eastern North Arm where significant changes have occurred in the thermal regime. The pattern of changes recorded in the estuary closely resemble changes noted in overseas studies of disturbed estuarine regions.

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APPENDIX I

SPECIES LIST 1972-1985

+ recorded Species:	YEAR:				
	Pre-1981	1981	1982	1983	1985
POLYCHAETES					
Naineris grubei australis Hartman	+	+	+	+	+
Scoloplos cylindrifer Ehlers	+	+	+	+	+
Leitoscoloplos bifurcatus (Hartman)	+		+		+
Scolaricia sp.		+	+		
Nephyts australiensis (Fauchald)	+	+	+	+	+
Cirriformia punctata (Grube)	+	+	+	+	+
Lumbrineris sp. 1	+	+	+	+	+
Lumbrineris sp. 2					+
Eunice australis Quatrefages	+	+	+	+	
Eunice antennata (Savigny)	+				
Lysidice sp.				+	
Marphysa sp.			+		
Nematonereis sp.					+
Schistomeringos sp.	+		+	+	+
Diopatra dentata Kinberg	+	+	+	+	+
Neanthes vaalii Kinberg	+	+	+	+	+
Neanthes cricognatha (Ehlers)	+			+	
Nereis cockburnensis Augener			+		
Olganereis edmondsi (Hartman)	+		+	+	+
Australonereis ehlersi (Augener)	+			+	
Ceratonereis transversa Hutchings	+			+	
Perinereis nuntia (Grube)		+	+	+	
Perinereis amblyondonta (Schmarda)			+		
Nereidae				+	
Barantolla lepte Hutchings	+	+	+	+	+
Capitella capitata (Fabricius)					+
Pseudopolydora sp.	+		+	+	+
Boccardia chilensis Blake & Kudenov					
Syllis gracilis Grube	+		+	+	+
Myrianida sp.	+				
Harmothoe praeclara (Haswell)	+	+	+	+	+
Glycera americana Leidy			+	+	
Ophiodromus sp.				+	
Abarenicola affinis clarki Wells			+	+	
Ampharetidae					
Chaetopterus variopedatus (Reiner)	+		+		+
Armandia intermedia Fauvel		+			
Sabellidae	+			+	
Dorvillea sp.					+
Terebellinae		+		+	+
NEMERTEA					
Nemertean spp.	+	+	+	+	+
PLATYHELMINTHES					
Latocestus sp.	+	+			
BIVALVES					
Xenostrobus inconstans (Lamarck)	+	+	+	+	+
Tellina deltoidalis Lamarck	+	+	+	+	+
Irus crebrelamellatus (Tate)	+	+	+	+	+
Laternula recta (Reeve)	+	+	+	+	+
Katelysia scalarina (Lamarck)	+	+	+	+	+
Katelysia peronii Lamarck	+	+	+	+	+
Spisula trigonella (Lamarck)	+	+	+	+	+
Brachidontes erosus (Lamarck)	+	+	+	+	+
Ostrea angasi Sowerby	+				
Anomia trigonopsis Hutton	+				
Sanguinolaria biradiata (Wood)					+
Eumarcia fumigata (Sowerby)	+				+
Pinna bicolor Gmelin	+				
GASTROPODS					
Niotha pyrrhus (Menke)	+				
Nassarius burchardi (Philippa)	+	+	+	+	+
Nassarius pauperata (Lamarck)	+	+	+	+	+

	YEAR:				
Species:	Pre-1981	1981	1982	1983	1985
Bedeva paivae (Crosse)	+	+	+	+	+
Salinator fragilis (Lamarck)	+	+	+	+	+
Salinator solidus (von Martens)	+				
Batillaria estuarina (Tate)	+				
Batillaria diemenensis (Qouy & Gaimard)		+			
Diala lauta A. Adams		+			
Diloma sp.		+			
Quibulla tenuissima Sowerby			+	+	
Austroliotia densilineata (Tate)				+	
Opisthobranchia	+				+
Monodonta constricta Lamarck				+	
Clanculus sp.					+
Asteracmea sp.					+
Natica sp.					+
Nudibranchiata					+
CHITONS					
Stenochiton longicymba Blainville					+
CRUSTACEANS					
ISOPODS					
Paridotea munda (Hale)	+				
Dynamenopsis sp.			+	+	
Cerceis sp.		+	+		
Euidotea bakeri (Collinge)	+		+	+	
Cymodoce longicaudata (Baker)		+	+		
Zuzara venosa (Stebbing)	+			+	
Exosphaeroma sp. 1	+				+
Exosphaeroma sp. 2	+				
AMPHIPODS					
Ericthonius pugnax (Dana)	+				
Maera mastersii (Haswell)			+		
Elasmospus bampo Barnard	+	+	+		
Amphipod sp. A					+
Cymadusa filosa Barnard	+				
Cymadusa sp.	+				
Allorchestes compressa (Dana)	+	+	+		
DECAPODS					
Crangon socialis (Heller)	+	+	+	+	
Leander serenus (Heller)			+		
Processa sp.	+				
Penaeus latisulcatus (Kishinonye)		+			+
Philyra laevis (Bell)	+	+	+	+	+
Pilumnus fissifrons (Stimpson)		+	+	+	+
Halicarcinus rostratus (Haswell)	+				
Phlyxia intermedia (Miers)	+				
Heteropanope serratifrons (Kinahan)	+				
Naxia aurita (Latreille)	+				
Helograpsus haswellianus (White legge)			+	+	
Petalomera depressa (Baker)	+				
Nectocarcinus sp.	+				
Ceratoplax punctata (Baker)					+
Callianassa ceramica (Fulton & Grant)	+				
STOMATOPODS					
Squilla laevis (Hess)	+				
TANAIDS					
Apseudes australis (Haswell)	+				
Tanaidae	+	+	+	+	+
MYSIDS					
Paranchialana angustata (Sars)				+	
CIRRIPEDS					
Balanus amphitrite Darwin					+
Elminius modestus	+				
COPEPODS					
Copepods					+

	YEAR:				
Species:	Pre-1981	1981	1982	1983	1985
CNIDARIANS					
Anthothoe albocincta (Stuckey)	+	+	+	+	+
Epiactis sp.	+	+			
PISCES					
Nesogobius hinsbyi (McCulloch & Ogilby)		+	+		
Ammotretis elongatus McCulloch	+			+	
Gobius bifrenatus Kner				+	
ECHINODERMS					
Ophionereis sp.			+	+	
Leptosynapta dolabrifera (Stimpson)				+	
Cricophorus nutrix (Stuckey)				+	
Ophiuroidea				+	